Solgel route to Erbium-doped microlasers and Raman microlasers on-a-chip

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Abstract: Ultra-high-Q microresonators are fabricated on silicon chips by the solgel technique. Using wafer-based processing and selective reflow, we create toroid-shaped Er-doped microlasers directly from Er-doped solgel layers and Raman microlasers from undoped silica solgel layers.

OCIS codes: (140.3500) laser, erbium; (140.4780) optical resonators; (160.6060) Solgel

1. Introduction

The solgel process for preparing silica and silicate from a metal alkoxide precursor has been an important platform for many applications [1-2]. It combines control of composition and microstructure at the molecular level with the ability to shape materials in bulk, fiber, powder and thin film forms. On the other hand, photonic devices using silica layers deposited on silicon chips are the basis for numerous photonic devices. Recently, a silica-based resonator structure in the form of a microtoroid has demonstrated unprecedented Q factors in the range of 100 million [3]. In this work, the process flow for this resonator is modified using the solgel method. In one series of experiments, Erbium doped solgel films are used as the base material for microtoroid formation. The subsequently processed devices function as low threshold micro lasers. In a second set of experiments, pure silica solgel layers serve as the base material and are processed into ultra-high-Q Raman microlasers. Both of these cases demonstrate the ability to use spin coating of sol gel films as a processing alternative to deposition or oxidation methods for silica layer formation.

2. Fabrication

The solgel solution was prepared by hydrolyzing tetraethoxysilane e (TEOS) using water in acidic conditions with the molar ratio of water to TEOS around 1~2. Er ions were introduced by adding $Er(NO)_3$ to achieve the desired Er concentration. After reaction at 70°C for three hours, a viscous solution was formed. The silica solgel film was then deposited on a Si substrate by the spin-coating method. Multi-coating was used to build up thickness. After each coating cycle, the chip was annealed at 1000°C for three hours. Subsequent to the spin coat and anneal step, processing of microtoroids proceeded as described in reference [2]. Circular silica pads were created on the Si wafer through a combination of lithography and etching. Subsequently, these pads served as an etch mask for isotropic silicon etching using XeF_2. The silica disks are left supported by narrower silicon posts. A CO_2 laser is then used to selectively reflow the silica disks, during which surface tension causes the disks to collapse into toroids. The exceptionally smooth surface of the toroid cavities endows these structures with their ultra-high-Q properties [3]. Fig. 1 depicts the fabrication process flow of the microlasers beginning with the solgel layers on the Si wafer.

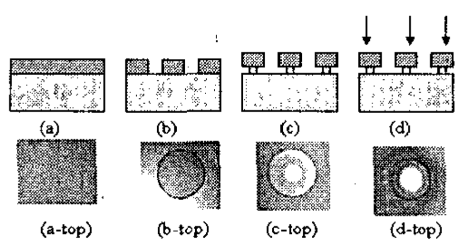

Fig. 1. Process flow for creation of solgel microcavities on a Si wafer in schematic side view (above) and photomicrograph plane view (below). (a) Solgel layer is spun on Si wafer; (b) circular pads are etched; (c) XeF_2 isotropic silicon etch; (d) CO_2 laser reflow.

3. Experiment

The principle diameter of the microtoids studied in this work ranged from 50 to 60 μm. A fiber taper with a waist diameter of 1-2 μm is aligned along the equatorial plane of the microtoroid to couple light in and out of the microcavity. To vary the air gap between the microcavity and the taper, the sample chips were mounted on a three-axis translator for position control. Tunable, single frequency, narrow linewidth (<300 kHz) external-cavity lasers at both 980 nm band and 1480 nm band were used as the pump source. Fig. 2 shows the typical laser spectrum of an Er-doped microtoroid laser fabricated using an Er-doped solgel layer spun on the silicon chip. The measured laser output power plotted versus the absorbed pump power is presented in the inset of Fig. 2.

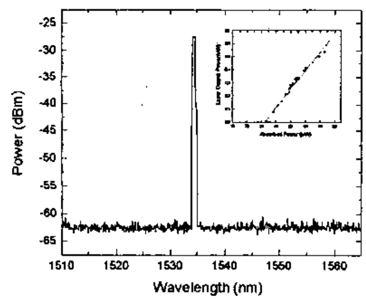

Fig. 2. Laser emission spectrum of the Er-doped microtoroid laser. Inset: Laser output power versus absorbed pump power

In ultra-high-Q microcavities Raman oscillation at low pump powers is possible even in linear media such as silica [4]. For this purpose, a microtoroid cavity was fabricated from the undoped solgel layer. Fig. 3 shows a typical Raman laser spectrum of the cavity. The Raman microtoroid laser was excited well above threshold using a pump power in the milliWatt range. In the figure, the pump wave is at 1451 nm and Raman lasing occurs near 1550nm. The inset to figure 3 is a micrograph showing the microtoroid-taper coupling system.

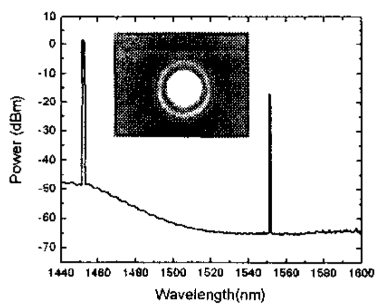

Fig. 3. Spectrum of a Raman microtoroid laser with principal diameter of 55 μm. The pump power is 1.2 mW at 1451 nm and Raman oscillation occurs at 1551 nm. Inset: micrograph of a solgel microtoroid coupled to a fiber taper.

4. Conclusion

By using solgel process, we could create both Er-doped microlasers and Raman microlasers on a chip. The solgel process provides a versatile way to create silica-based devices with precise control of the composition.

References

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